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ARL-STRUC-TM-489 AR-005-526

AD-A201 074

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Aircraft Structures Technical Memorandum 489

AN EXAMINATION OF THE FATIGUE METER RECORDS FROM THE RAAF CARIBOU FLEET (U)

by

Douglas J. Sherman

Approved for Public Release

JULY 1988

88 12 6 041

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AN EXAMINATION OF THE FATIGUE METER RECORDS FROM THE RAAF CARIBOU FLEET (U)

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SUMMARY

Load spectra for the Australian fleet of Caribou transport aircraft are presented and compared with the ESDU 69023 (discrete gust) model and the US MILSPEC 8861A (power spectral) model.

The gust load spectra are best predicted by the US MILSPEC model. The most frequent manoeuvre loads are well predicted by the ESDU model, although the rarer, high amplitude, manoeuvre loads occur more frequently than that model predicts.

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CONTENTS

1. INTRODUCTION

In the early 1960's the Royal Australian Air Force ordered 25 Caribou I aircraft from the Canadian de Havilland Company. These aircraft came into service in 1964, and at the present time 21 of these aircraft are still on the register.

The aircraft were all fitted with M1946 fatigue meters (Mk11), and these meters are, in general, read at the end of each flight.

Since the beginning of March 1975 these fatigue meter data have been entered into a computer, and the present report is based on an analysis of the computerised data base extending from 3 March 1975 to 25 August 1984. This period includes data from just over 100 000 hours of flying - a very large data base - so the results have sufficient significance to distinguish between different gust load prediction methods.

2. FATIGUE METER COUNTS

In Appendix 1 an outline is given of the format of the fatigue meter data records, and of the checks which were applied to them. The main results are shown numerically in Tables A1 to A5, and graphically in the corresponding Figures 1 to 5. These tables and figures show the load spectra measured by the fatigue meters when the records are classified according to:

1. Calendar year
2. Calendar month
3. Geographic area
4. Type of flying mission
5. Individual aircraft

[NOTE: Tables A3 and A4 also show the meanings of the area and mission codes.]

3. SPECIAL FACTORS

Of the various types of flying missions, type 4 (Display) is clearly more severe than all other types. At the two highest "g" levels, the loading frequencies are, respectively, 20 and 30 times the corresponding average frequencies for all types of flying. If a disproportionate amount of "display" flying occurs near the home base of Richmond, this might distort any geographic variation in the occurrence of turbulence which we might seek to infer from the data. However, Table A6 shows that no more than 0.8% of the time in any area (including Richmond) is spent on display flying. Even though display flying is, at the extreme, 20 or 30 times as severe as the rest, it will still only contribute 16% or 24% of the total fatigue spectrum at Richmond. Moreover, the area to area variation in the contribution of display flying is about half this, because in almost all areas display flying occupies at least 0.4% of the time.

Australia. (Jer)

A more significant factor is the amount of "General Flying" (Mission Code 1) done in the various areas. Table A6 shows that "General Flying" accounts for nearly 50% of the flying from Richmond but only about 10% of the flying in other areas. Apparently, general flying includes training, a large part of which will involve touch

Par 1

and go practice which implies low level flying and a corresponding high exposure to turbulence. Accordingly, it is not surprising that the Richmond area (Code 1) has one of the most severe load spectra on both the "above 1g" (manoeuvre dominated) side, and the "below 1g" (turbulence dominated) side.

4. DISCUSSION

At least part of the scatter between the various curves on each graph is due to the random nature of flight loading. The higher the quantity of data on which a curve is based, the smaller will be the scatter. The usual measure of variability is the standard deviation, which, for most common probability distributions, is inversely proportional to the square root of the amount of data involved. Thus, less scatter is expected for curves based on more flying hours. Also, less scatter is expected for the inner (near "1g") sections of the load spectra than for the outer sections where the number of exceedances per hour is much smaller.

An idea of the intrinsic random scatter can be obtained from Figure 1 and Table A1 which show, year by year, the average spectrum for the whole fleet. On the right hand (manoeuvre dominated) side, the spectra for 1975 and 1976 are clearly lower than for all subsequent years. It is likely that there is a determinable reason for this, as the left hand (or turbulence dominated) side shows no such difference. For all later years there is no regular pattern. This is remarkable because military aircraft usually show a pattern of increasing severity with time, as new flying techniques are introduced. (It is possible that the apparent increase after 1976 represents such an introduction of a new flying technique.)

The scatter in the post 1976 flying covers a range of about 1 to 1.5 from least to greatest, at the 0.05 g and 1.95 g levels.

A corresponding amount of random scatter is seen in Figure 5 and Table A5 which show variations from aircraft to aircraft. The scatter is greater than in Figure 1, covering a range of about 1 to 2 from least to greatest at the 1.95 g level. However, since there is about half the number of flying hours to each aircraft in Figure 5 that there is for each calendar year in Figure 1, this increased scatter is about the expected magnitude. (i.e. Scatter in Fig 5 = $\sqrt{2}$ x scatter in Fig 1.)

The month to month scatter in Figure 2 is considerably greater than the scatter in Figures 1 or 5, so there is clearly a seasonal variation in spectral severity. (The evidence for this is reinforced by the high correlation between adjacent months.) This scatter is almost certainly due to the seasonal variation in turbulence occurrence because the scatter at the 1.55 g and 1.95 g levels (where manoeuvres will make a significant contribution) is rather less than the scatter at 0.45 g and 0.05 g which are expected to be dominated by turbulence. Turbulence is strongest in spring and early summer (September - January) with a maximum in October, and least severe in autumn and early winter (April - July) with a minimum in June and July. On the left hand side of the spectra, the turbulence encountered in the most severe month is generally 3 or 4 times as severe as that in the least severe month. Higgs (1961)[1] found similar variations for two DC-6 aircraft in scheduled passenger service flying, and so did Bruce and Hooke (1961)[2] for ten Viscount aircraft.

The geographic variations in Figure 3 also seem to be significant because the scatter is greater than the year to year scatter in Figure 1, despite the fact that the amount of time spent flying in most regions is rather higher than the time flown by the entire fleet in one calendar year.

The most severe regions for turbulence are:

1. Richmond

7. S.A. and South W.A.

while the least severe regions are:

2. Papua and New Guinea

4. South Queensland and North NSW

The fact that Richmond is amongst the most severe, whilst its surrounding region, South Queensland and North NSW is one of the least severe, emphasises the point made earlier that the actual types of flying carried out in the different regions are a significant factor in the turbulence experienced. Rather more flying around Richmond is at low level than in regions involving long sorties.

The load spectra for the different types of flying indicate that display flying (type 4) involves a large number of manoeuvres giving high loads at all levels, but most noticeably at the loads of 1.55 g and above. For the other types of flying, only types 1, 3 and 6 have enough data to indicate significant differences. For loads below 1 g, where turbulence is expected to dominate, Army support (type 6) is most severe - presumably because of its high percentage of low level flying. General flying (type 1) is of intermediate severity, and cruising flight (type 3) is of least severity.

For loads above 1 g, where manoeuvres are significant, general flying is most severe, army support is intermediate, and cruising flight is least severe.

5. COMPARISON WITH EXPECTED TURBULENCE SPECTRA

The RAAF (Borysewicz, 1986)[3] has estimated the fraction of time spent at various altitude/airspeed combinations for each of the different types of flying mission into which the fatigue meter data is classified. From these estimates and the relative times spent on each mission (Table A4), the flight profile shown in Table A7 has been constructed.

From this profile, using a computer program EXCG, developed by the writer, the flight load spectra expected according to the discrete gust procedure defined by ESDU 69023 (1979)[4], and the power spectral method defined by MILSPEC A8861A (1971)[5] have been calculated. The results for these two different methods are shown in Tables A8 and A9, and in Figures 6 and 7 respectively.

The discrete gust procedure defined by ESDU 69023 is intended to predict the total load spectra, due to gusts and manoeuvres, experienced by a transport aircraft in regular usage. On the other hand, the power spectral procedure, defined in MILSPEC A8861A, is an estimate of turbulence loading only: the manoeuvre loading has to be estimated separately and added.

The left hand sides of the measured load spectra (which are assumed to be primarily due to turbulence) match fairly closely with the curves, shown in Figure 7, which were computed by the power spectral method, but are considerably lower than the curves, shown in Figure 6, which were computed by the discrete gust method of ESDU 69023. (The differences between the 2 methods are discussed in Appendix 2.)

For the Caribou data, the MILSPEC model is the best predictor of the gust loading. The curve of "expected exceedances" shown in each of the figures is the MILSPEC prediction of the gust loading for the total flight profile shown in Table A7.

The right hand sides of the measured load spectra (which are assumed to be significantly affected by manoeuvres) are fairly well estimated by the ESDU 69023 model, although the highest loads occur much more frequently than that model predicts. This is to be expected because the Caribou, being used in a military role, undergoes more severe manoeuvres than a normal civil transport.

6. CONCLUSIONS

The measured gust load spectra for the Australian Caribou fleet are shown in Tables A1 to A5 and, graphically, in Figures 1 to 5. In this report we have studied how well those spectra are predicted by the ESDU 69023 data sheet, which is based on the discrete gust theory, and by the U.S. MILSPEC 8861A, which is based on power spectral theory.

1) The two methods predict that very similar numbers of gusts will be encountered in low altitude flying.

2) The two methods predict gust-to-load transfer characteristics which differ by only about 20% in the case of the Caribou.

3) This relatively small difference in transfer characteristics results in a very large difference in the numbers of predicted gust loads. Results of the two methods may differ by factors in excess of 5.

4) For the Caribou, the numbers of gust loads actually experienced agree well with the U.S. (power spectral) code: they are greatly over-estimated by the ESDU (discrete gust) data sheet.

5) This agreement, in the case of the Caribou, does not imply that the power spectral code is always to be preferred. In the case of the F111 the two methods produce almost identical transfer characteristics. It is desirable to perform further analyses for other aircraft types for which extensive gust load data and reliable flight profiles are known.

6) At greater heights the data available when the two codes were formulated did not include very large numbers of exceedances of the larger gust velocities. The two codes predict exceedances which differ, in some of the more extreme cases, by factors well over 10. Data from large volume data banks, such as are envisaged for the ACARS project (Sherman, 1985)[6] are needed to reliably establish these gust velocity occurrence frequencies in the Australian environment.

7) There are strong seasonal variations in the numbers of gust loads experienced in Australia. The maximum load frequencies, experienced in spring and early summer may be up to 4 times the minimum load frequencies experienced in late autumn and early winter.

APPENDIX 1
CARIBOU FATIGUE METER DATA

1. FORMAT OF COMPUTERISED FATIGUE METER RECORDS

Fatigue meter data are recorded in an 80 column format (see also RAAF, 1976[7]) as follows:

Columns	Field
1–4	Unit Identification
5–9	Aircraft Serial Number [All Caribou aircraft serial numbers commence with 04 in columns 5 & 6.]
10–12	Sheet Serial Number
13	Flight Number
14–19	Date of flight in form DDMMYY [e.g. 21 May 1974 is 210574]
20–21	Fuel weight at start up in hundreds of pounds
22–24	All up weight at take-off in hundreds of pounds
25	Operation area code [See Table A3]
26	Mission code [See Table A4]
27–28	Number of landings
29	Control Code [See below]
30–44	Reserved
45–76	Acceleration counter readings. There are eight 4-digit numbers corresponding to the eight different counters. [See below.]
77–80	Duration of flight in hours. Column 79 always contains a decimal point.

Control Codes

0	–	Normal data
1	–	Out of sequence sheet, serial numbers, and flight numbers. First set of counter readings after a calibration or change of fatigue meter.
2	–	Nil meter readings. [Due to faulty meter.]
3	–	One or more fatigue meter counters has passed the maximum count of 9999.
4 or more	–	Unknown anomaly has been inferred in the readings.

Acceleration Counters

The cocking and firing levels for the eight acceleration counters are symmetric about 1 g, as follows:

Counter	Cocking (g)	Firing (g)
1	-0.35	+0.45
2	+0.05	+0.55
3	+0.45	+0.75
4	+0.75	+1.05
5	+1.25	+0.95
6	+1.55	+1.25
7	+1.95	+1.45
8	+2.35	+1.55

2. CHECKING THE DATA

The RAAF data entry program involved various compatibility checks. All checks mentioned here are additional to the RAAF's own checking procedure. Since the counters are cumulative, the numbers of acceleration counts during each flight are obtained by subtracting the counter readings at the end of the flight from those at the end of the previous flight. The data from any flight were rejected if:

(a) the control code for that flight was not equal to 0 or 3, or

(b) the number of acceleration counts at any level was negative, or

(c) the number of acceleration counts at any level exceeded a maximum allowable value for that level. For the eight acceleration levels the maximum allowable values were, respectively, 100, 500, 1000, 5000, 5000, 1000, 500, 100.

APPENDIX 2

GUST LOAD MODELS

1. DIFFERENCES BETWEEN GUST LOAD PREDICTION MODELS

Table A10 shows the numbers of gust loads predicted for the Caribou aircraft at various heights by using both the "discrete gust" and the "power spectral" methods of computation. In general, there are considerable differences between the results of the two methods. The MILSPEC A8861A (power spectral) method has been shown, in the body of this report, to be a much better predictor of the gust loading experienced by the Caribou fleet than the ESDU 69023 (discrete gust) method. However, the fact that there is such a big difference between the two prediction methods when applied to the Caribou is surprising in view of the fact that calculations for the F111 (Sherman, 1987[8]) showed the two methods to produce very similar results (at least for an altitude of 500 ft and a Mach Number of 0.75).

In comparing the two models, we may distinguish three parts to the problem:

(a) The estimation of frequency of gusts of various severity, and

(b) the estimation of the response of the aircraft, and

(c) resulting from (a) and (b), the estimation of frequency of loads of various severity.

In this study, the "load" we have considered is the vertical acceleration at the centre of gravity.

2. ESTIMATION OF FREQUENCY OF GUSTS AT 500 ft ALTITUDE

At an altitude of 500 ft both methods give fairly similar estimates for the frequency of vertical gusts. Figure 8 shows the ratio, R, of the number of gust velocity exceedances estimated by the power spectral method, to the number of gust velocity exceedances estimated by the discrete gust method. Because the ESDU discrete gust method includes manoeuvres also, and because these manoeuvres induce primarily positive loads (upgusts), the ratio R is defined so as to exclude manoeuvres:

$$R = \frac{\frac{1}{2} \times \text{Power Spectral exceedances of magnitude U}}{\text{Discrete gust exceedances of \underline{down} gusts U}}$$

In all cases U is defined as the sea-level equivalent vertical gust magnitude. The variation between similar curves in Figure 8 is due to the variation* of M_0 with

* The N_0 value used for this purpose is the value appropriate for vertical acceleration at the centre of gravity, so as to produce comparable statistics to the derived equivalent gust of the discrete gust method. The calculations were performed for an aircraft geometrically the same as the Caribou, but with varying mass. Some mass parameter values are outside the range of what is possible with a real Caribou aircraft.

the mass parameter, μ. [N_0 is the frequency of upcrossing of the mean level (1g in the case of load and 0 in the case of vertical gust velocity). The mass parameter μ is given by

$$\mu = \frac{2\ (W/S)}{\rho\ c\ g\ a}$$

where W is aircraft weight, S is the reference (wing) area, ρ is air density, c is the aerodynamic mean chord, g the acceleration due to gravity and a the slope of the lift coefficient vs angle of attack graph.] However, all the curves are fairly flat and have ordinates reasonably close to 1.0. The discrete gust method estimates greater numbers of exceedances of the large gusts if no weather radar is fitted, but the power spectral method makes no such allowance. Thus, as Figure 8 shows, R is a little smaller for large gusts if there is no weather radar.

3. ESTIMATION OF FREQUENCY OF GUSTS AT OTHER ALTITUDES

Figures 9 and 10 show values of the ratio R, for a range of altitudes, when the discrete gust calculations are done for aircraft without weather radar (Fig 9a,b), and for aircraft fitted with weather radar (Fig 10a,b). The big differences between figures 9 and 10 emphasise that there appears to be a deficiency in the power spectral model in not recognising the significance of weather radar installation. One of the realities is, of course, that aircraft which fly above 10,000 ft are much more likely to have weather radar than those limited to lower altitudes. In particular, the low values of R shown in Figure 9b for altitudes of 40,000 ft and 50,000 ft are most unlikely to be realised because aircraft flying this high are almost certain to be fitted with weather radar. However, in general, it seems that for altitudes above 2,000 ft the power spectral code predicts vastly higher frequencies of gust loading than does the ESDU discrete gust procedure. The higher the gust velocity the higher the factor by which the power spectral method exceeds the discrete gust method. It is, of course, these high gust velocities at high altitudes which occur least often, and so are least reliably estimated from the existing data bases. In fact, it is only the recent work reported, for example, by Coupry (1985)[9] and de Jonge et al (1986)[10], which has a sufficient data base to indicate reliable statistics for these rare gust occurrences.

4. ESTIMATION OF AIRCRAFT RESPONSE

In the ESDU discrete gust method the vertical acceleration increment of the aircraft, Δn, is proportional to the derived equivalent gust velocity U_{de}. The ratio $U_{de}/\Delta n$ is a function of aircraft configuration, air speed and the mass parameter μ.

In the power spectral method, the relation between vertical acceleration increment, Δn, and "true" gust velocity, U_T, is indicated by the parameter

$$A = \frac{\sigma_{\Delta n}}{\sigma_{U_T}}$$

The sea level equivalent gust velocity U_e is equal to U_T multiplied by the square root of the density ratio, so

$$\sigma_{U_e} = (\rho/\rho_o)^{1/2} \, \sigma_{U_T}$$

Thus $\frac{U_{de}}{\Delta n}$ is comparable to (but not precisely the same as)

$$\frac{(\rho/\rho_o)^{1/2}}{A}$$

Again, this quantity is a function of aircraft configuration, air speed, and the mass parameter μ.

These two transfer characteristics, $U_{de}/\Delta n$ and $\frac{(\rho/\rho_o)^{1/2}}{A}$ have been computed for hypothetical aircraft with the same configuration and size as the Caribou and the F111, but with varying mass. The variation with mass parameter, μ, is shown in Figure 11. The large arrow A marks the typical value of μ for the Caribou, and the arrow B marks the typical value of μ for the F111. It happens that the transfer characteristics for the F111 with a typical mass parameter are almost identical for the discrete gust or the power spectral method. On the other hand, for the Caribou with a typical mass parameter, the two computation methods produce significantly different transfer characteristics.

The typical spectra shown in Figures 1 to 7 fall very steeply with increasing load. A 20% variation in $U_{de}/\Delta n$ causes a 20% variation in the gust velocity which is calculated to correspond to a given load. This can lead to a variation by a factor of 10 in the estimated frequency of occurrence of the load.

5. ESTIMATION OF FREQUENCY OF LOADS

Figure 12 shows that, for the Caribou, at a realistic mass parameter of 12.5, the number of loads estimated by the power spectral method can be as low as 1/10 the number estimated by the discrete gust method.

On the other hand, Figure 13 shows that, for the F111 at a realistic mass parameter of 37.5, the number of loads estimated by the two methods is the same within a factor of about 1.5.

6. REASONS FOR DIFFERENCES

The reasons for these critical differences in transfer characteristics have been examined by Noback (1982)[11]. He concluded that the main cause of discrepancy between the two methods is the difference in the relation between gust velocity and gust length in the two gust models. Implicit in this is also the ratio of aircraft chord to gust length, as the British discrete gust method considers gusts with a fixed length of 100 ft; the American discrete gust method considers gusts with a length of 12½ chords, and the power spectral method considers continuous turbulence in which the ratio between long wave length component amplitudes and short wave length component amplitudes is determined by the shape and integral scale of the turbulence spectrum.

7. APPLICATION TO AUSTRALIAN DATA

Sherman (1981)[12] reviewed the available Australian data and concluded that it was not incompatible with ESDU data item 69023. [That review pooled positive and negative gusts in order to determine a value of ℓ_{10}, the distance between 10 ft/sec gusts. The ESDU data item has been shown to be a good predictor of the inner part of the right hand side of the Caribou spectrum which is caused by manoeuvres as well as turbulence, and even if the left hand side of a load spectrum is in error by a factor of 4 or 5, it will make only a small change in the value of ℓ_{10} when it is pooled with the larger right hand side. However, Sherman (1981)[12] also examined the ratio of upgusts to downgusts for the Australian data. There was a large scatter in the ratio data, but the ESDU curve fitted most of the data as well as any other curve.]

It happens then, that in the case of the Caribou aircraft, characteristics computed by the power spectral method provide a better predictor of turbulence loading than those computed by the discrete gust method. However, this conclusion may not extend to all aircraft types. Cases of different aircraft types need to be examined also.

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TABLE A1

Fatigue Meter Exceedances per Hour and Flying Time per Year
For all Caribou Aircraft flown between
March 1975 and August 1984

Year	Exceedances per Hour of Fatigue Meter Level 1 -0.35g	2 +0.05g	3 +0.45g	4 +0.75g	5 +1.25g	6 +1.55g	7 +1.95g	8 +2.35g	Hours
1975	10.39E-05	58.18E-04	21.81E-02	69.20E-01	22.43E+00	99.83E-02	43.12E-03	34.29E-04	9625.2
1976	25.56E-05	54.53E-04	19.80E-02	85.97E-01	26.18E+00	96.56E-02	44.39E-03	33.23E-04	11737.3
1977	25.15E-05	50.30E-04	22.21E-02	95.52E-01	34.37E+00	16.52E-01	12.88E-02	13.92E-03	11929.1
1978	52.84E-05	57.25E-04	16.89E-02	66.07E-01	26.79E+00	12.89E-01	11.18E-02	12.86E-03	11354.0
1979	17.65E-05	78.54E-04	25.35E-02	96.24E-01	32.33E+00	16.20E-01	14.79E-02	22.77E-03	11332.0
1980	26.75E-05	54.39E-04	20.47E-02	82.07E-01	28.02E+00	13.03E-01	10.41E-02	12.66E-03	11215.5
1981	27.80E-05	61.17E-04	22.78E-02	80.89E-01	29.29E+00	13.07E-01	95.19E-03	91.76E-04	10789.5
1982	21.64E-05	64.93E-04	26.83E-02	97.86E-01	32.52E+00	15.14E-01	90.47E-03	96.31E-04	9240.8
1983	53.01E-05	73.16E-04	23.38E-02	92.63E-01	33.07E+00	13.66E-01	92.46E-03	11.88E-03	9431.4
1984	78.44E-05	70.60E-04	25.06E-02	94.66E-01	31.21E+00	15.49E-01	10.69E-02	14.12E-03	5099.5
Mean/Tot	31.45E-05	61.52E-04	22.19E-02	85.59E-01	29.54E+00	13.48E-01	96.95E-03	11.36E-03	101754.2

TABLE A2

Fatigue Meter Exceedances per Hour and Flying Time per Month
For all Caribou Aircraft flown between
March 1975 and August 1984

Month	Exceedances per Hour of Fatigue Meter Level 1 -0.35g	2 +0.05g	3 +0.45g	4 +0.75g	5 +1.25g	6 +1.55g	7 +1.95g	8 +2.35g	Hours
Jan	.00E+00	80.54E-04	27.20E-02	98.25E-01	33.89E+00	15.26E-01	10.19E-02	78.17E-04	4221.3
Feb	12.93E-05	40.09E-04	18.97E-02	87.81E-01	30.87E+00	13.06E-01	90.78E-03	93.10E-04	7733.4
Mar	28.55E-05	52.34E-04	20.90E-02	81.49E-01	31.22E+00	14.37E-01	12.00E-02	19.79E-03	10509.1
Apr	24.81E-05	34.74E-04	13.06E-02	58.90E-01	23.15E+00	10.11E-01	85.35E-03	93.05E-04	8060.5
May	59.99E-05	57.99E-04	13.42E-02	55.51E-01	20.61E+00	10.21E-01	92.18E-03	13.30E-03	10002.5
Jun	30.15E-05	33.16E-04	11.12E-02	44.69E-01	16.34E+00	79.19E-02	63.61E-03	51.25E-04	9951.4
Jul	20.53E-05	33.87E-04	10.67E-02	48.06E-01	20.04E+00	89.50E-02	84.89E-03	86.23E-04	9741.9
Aug	10.39E-05	45.72E-04	17.32E-02	71.81E-01	25.99E+00	11.49E-01	85.30E-03	11.64E-03	9624.3
Sep	45.16E-05	67.74E-04	27.35E-02	10.15E+00	33.67E+00	15.26E-01	90.54E-03	90.32E-04	8857.7
Oct	22.15E-05	11.19E-03	44.16E-02	16.10E+00	50.09E+00	22.04E-01	12.65E-02	13.62E-03	9028.3
Nov	74.54E-05	93.71E-04	35.65E-02	12.17E+00	38.10E+00	18.29E-01	11.05E-02	12.35E-03	9390.9
Dec	21.56E-05	13.15E-03	38.88E-02	13.58E+00	40.28E+00	19.15E-01	12.92E-02	14.88E-03	4637.5
Mean/Tot	31.45E-05	61.52E-04	22.19E-02	85.59E-01	29.54E+00	13.48E-01	96.95E-03	11.36E-03	101758.7

TABLE A3

Fatigue Meter Exceedances per Hour and Flying Time per Area
For all Caribou Aircraft flown between
March 1975 and August 1984

Area	Exceedances per Hour of Fatigue Meter Level								Hours
	1	2	3	4	5	6	7	8	
	-0.35g	+0.05g	+0.45g	+0.75g	+1.25g	+1.55g	+1.95g	+2.35g	
0	.00+000	24.75-004	22.03-002	75.25-001	27.33+000	90.84-002	59.41-003	12.38-003	404.0
1	32.29-005	84.68-004	29.38-002	10.50+000	37.59+000	20.53-001	17.30-002	19.05-003	27869.3
2	.00+000	21.57-004	83.97-003	40.60-001	17.41+000	65.82-002	34.20-003	30.81-004	6490.4
3	.00+000	48.88-004	23.09-002	89.16-001	30.00+000	12.85-001	70.58-003	82.86-004	16776.1
4	57.39-005	45.91-004	22.88-002	98.29-001	33.92+000	12.98-001	77.14-003	98.38-004	12197.9
5	51.72-005	69.83-004	21.66-002	78.15-001	24.71+000	94.01-002	45.97-003	49.78-004	15466.9
6	56.01-005	11.76-003	23.30-002	65.18-001	24.85+000	12.56-001	56.57-003	33.61-004	1785.4
7	30.79-005	80.05-004	23.21-002	10.52+000	33.68+000	15.35-001	15.36-002	26.63-003	6496.3
8	.00+000	22.25-004	15.47-002	85.21-001	29.69+000	10.31-001	87.35-003	96.43-004	5392.4
9	56.31-005	49.55-004	11.10-002	36.83-001	12.54+000	62.94-002	44.03-003	37.16-004	8880.1
Mean/Tot	31.45-005	61.52-004	22.19-002	85.59-001	29.54+000	13.48-001	96.95-003	11.36-003	101758.7

Operational Area Codes

Area Code	Area
0	Unidentified
1	Richmond Local
2	Papua & New Guinea
3	Northern Queensland
4	South Queensland & North NSW
5	South NSW & Victoria
6	Tasmania
7	SA & South WA
8	NT & North WA
9	Other

TABLE A4

Fatigue Meter Exceedances per Hour and Flying Time per Mission
For all Caribou Aircraft flown between
March 1975 and August 1984

Mission	Exceedances per Hour of Fatigue Meter Level								Hours
	1 -0.35g	2 +0.05g	3 +0.45g	4 +0.75g	5 +1.25g	6 +1.55g	7 +1.95g	8 +2.35g	
0	.00+000	.00+000	14.61-002	77.49-001	33.89+000	96.95-002	39.84-003	.00+000	150.6
1	46.38-006	53.80-004	22.13-002	91.14-001	34.43+000	19.82-001	18.34-002	20.73-003	21559.4
2	.00+000	43.18-004	16.10-002	65.11-001	24.60+000	90.91-002	44.41-003	43.18-004	1621.3
3	33.27-005	51.39-004	18.32-002	69.78-001	22.66+000	86.42-002	45.27-003	40.11-004	54099.7
4	.00+000	21.81-003	76.50-002	14.34+000	53.49+000	77.50-001	18.84-001	37.24-002	596.1
5	81.12-005	17.04-003	51.03-002	15.78+000	49.92+000	21.34-001	94.91-003	17.04-003	1232.7
6	53.34-005	84.89-004	29.02-002	11.43+000	39.97+000	17.24-001	95.34-003	10.76-003	22499.3
Mean/Tot	31.45-005	61.52-004	22.19-002	85.59-001	29.54+000	13.48-001	96.94-003	11.36-003	101759.1

Mission Categories

Mission Code	Type of Flying
0	Unidentified
1	General Flying
2	IFR/Night
3	Cruising Flight
4	Display
5	Stols
6	Army Support

TABLE A5

Fatigue Meter Exceedances per Hour and Flying Time per Aircraft
For all Caribou Aircraft flown between
March 1975 and August 1984

	Exceedances per Hour of Fatigue Meter Level								
	1	2	3	4	5	6	7	8	
A/C	-0.35g	+0.05g	+0.45g	+0.75g	+1.25g	+1.55g	+1.95g	+2.35g	Hours
140	62.82-005	77.48-004	26.32-002	10.30+000	33.41+000	16.44-001	11.98-002	17.38-003	4775.4
152	40.85-005	10.21-003	26.64-002	10.37+000	24.20+000	11.58-001	84.16-003	63.32-004	4895.4
159	.00+000	47.97-004	19.79-002	79.35-001	26.09+000	11.62-001	94.02-003	13.91-003	4169.3
164	78.17-005	11.20-003	40.96-002	10.80+000	29.59+000	18.11-001	10.50-002	99.01-004	3837.9
173	.00+000	29.81-004	15.28-002	74.65-001	24.85+000	10.27-001	71.53-003	10.43-003	4026.0
179	20.91-005	83.66-004	29.89-002	10.24+000	37.42+000	16.35-001	97.46-003	11.50-003	4781.4
191	21.19-005	48.73-004	22.54-002	10.10+000	31.32+000	13.93-001	97.26-003	10.17-003	4719.5
195	.00+000	37.72-004	18.53-002	72.29-001	34.71+000	15.00-001	87.19-003	54.49-004	4771.4
199	.00+000	33.46-004	17.14-002	78.81-001	31.29+000	10.99-001	81.26-003	76.48-004	4183.9
204	23.61-005	63.74-004	21.79-002	83.45-001	25.28+000	11.28-001	10.22-002	19.12-003	4236.1
208	.00+000	10.72-003	25.54-002	93.24-001	33.97+000	15.64-001	12.63-002	19.81-003	4290.6
210	.00+000	38.59-004	17.92-002	79.29-001	28.63+000	11.63-001	78.90-003	79.33-004	4663.9
225	84.50-005	63.37-004	26.49-002	88.93-001	28.63+000	13.38-001	93.79-003	12.67-003	4733.8
228	19.36-005	52.28-004	20.39-002	81.51-001	29.44+000	13.21-001	11.10-002	11.62-003	5164.4
231	82.73-005	10.96-003	31.71-002	11.11+000	31.60+000	17.00-001	11.36-002	12.82-003	4834.8
234	23.26-005	30.24-004	13.31-002	57.06-001	24.61+000	10.00-001	66.99-003	95.37-004	4299.1
235	39.90-005	41.89-004	15.12-002	62.67-001	23.34+000	11.13-001	88.58-003	11.77-003	5012.6
236	42.06-005	39.96-004	16.70-002	76.12-001	26.87+000	12.53-001	83.91-003	71.50-004	4755.0
264	21.07-005	50.56-004	15.61-002	53.14-001	28.36+000	13.62-001	86.58-003	86.37-004	4747.1
275	37.79-005	77.47-004	27.13-002	99.85-001	32.36+000	13.88-001	93.53-003	77.47-004	5292.2
285	41.63-005	43.72-004	21.53-002	84.15-001	28.30+000	13.83-001	12.89-002	13.53-003	4803.7
299	41.97-005	60.86-004	18.53-002	86.93-001	34.17+000	14.61-001	11.58-002	16.16-003	4765.3
Mean/Tot	31.45-005	61.52-004	22.19-002	85.59-001	29.54+000	13.48-001	96.94-003	11.36-003	101758.8

TABLE A6

Percentage of flying hours in each area spent on various types of flying.

Mission Code	Area Code 0	1	2	3	4	5	6	7	8	9	All Areas
0	7.0	0.1	0.1	0.1	0.1	0	0.1	0.0	0.6	0.3	0.1
1	6.1	48.7	13.4	15.2	6.9	9.4	15.9	8.7	8.7	10.4	21.2
2	5.5	3.2	2.7	0.7	0.6	1.6	1.7	0.3	0.3	0.4	1.6
3	53.3	31.8	71.6	45.3	55.5	72.1	64.4	60.8	65.7	69.4	53.2
4	0.3	0.8	0.5	0.8	0.8	0.3	0.7	0.4	0.4	0	0.6
5	4.8	1.5	5.3	0.6	1.0	1.2	2.1	0.1	0.0	0.3	1.2
6	23.0	13.9	6.4	37.3	35.1	15.4	15.1	29.7	24.3	19.2	22.1
	100	100	100	100	100	100	100	100	100	100	100

TABLE A7

Estimated time flown at different Altitude/Airspeed combinations for different types of flying.

Type of Flying	Altitude (ft)	C.A.S. (Knots)	Time	Total Time
1	125	108	21	
	375	110	21	
	750	125	105	
	2000	125	10	
	7000	125	53	210
2	500	108	2	
	2000	125	3	
	7000	125	15	20
3	250	108	53	
	750	125	106	
	2000	125	50	
	7000	125	321	530
4	250	108	2	
	750	110	2	
	2000	125	1	
	5000	125	5	10
5	500	108	7	
	7000	125	3	10
6	250	110	22	
	750	125	66	
	2000	125	20	
	7000	125	112	220
Total Time - all types of flying				1000

TABLE A8

Fatigue Meter Exceedances per Hour
Estimated by ESDU Data Item 69023
For Caribou Aircraft flown according to
Flight Profile shown in Table A7.

Mission	Exceedances per Hour of Fatigue Meter Level 1 -0.35g	2 +0.05g	3 +0.45g	4 +0.75g	5 +1.25g	6 +1.55g	7 +1.95g	8 +2.35g	Hours
1	18.10-004	37.30-003	11.00-001	31.30-000	75.80+000	26.50-001	88.60-003	42.10-004	21000.0
2	13.00-004	23.80-003	63.00-002	16.90-000	31.80+000	11.50-001	41.90-003	22.10-004	2000.0
3	15.00-004	28.60-003	78.80-002	21.40-000	46.00+000	16.60-001	58.30-003	29.50-004	53000.0
4	10.60-004	22.70-003	70.20-002	21.10+000	44.20+000	14.20-001	44.60-003	20.00-004	1000.0
5	58.60-005	14.70-003	51.00-002	18.40+000	44.40+000	11.80-001	31.90-003	11.30-004	1000.0
6	16.60-004	32.50-003	91.60-002	25.20+000	56.70+000	20.30-001	70.10-003	34.80-004	22000.0
Mean/Tot	15.80-004	31.00-003	87.50-002	24.20-000	54.30+000	19.30-001	66.50-003	32.90-004	100000.0

TABLE A9

Fatigue Meter Exceedances per Hour
Estimated by U.S. MILSPEC A8861A (1971)
For Caribou Aircraft flown according to
Flight Profile shown in Table A7.

Mission	Exceedances per Hour of Fatigue Meter Level 1 -0.35g	2 +0.05g	3 +0.45g	4 +0.75g	5 +1.25g	6 +1.55g	7 +1.95g	8 +2.35g	Hours
1	4.06-004	7.90-003	4.99-001	32.50+000	32.50+000	4.99-001	7.90-003	4.06-004	21000.0
2	2.96-004	3.95-003	11.10-002	8.00+000	8.00+000	11.10-002	3.95-003	2.96-004	2000.0
3	3.54-004	5.51-003	20.80-002	16.85+000	16.85+000	20.80-002	5.51-003	3.54-004	53000.0
4	1.84-004	3.73-003	17.53-002	15.53+000	15.53+000	17.53-002	3.73-003	1.84-004	1000.0
5	1.85-004	3.54-003	19.70-002	19.05+000	19.05+000	19.70-002	3.54-003	1.85-004	1000.0
6	3.78-004	6.45-003	33.60-002	21.65+000	21.65+000	33.60-002	6.45-003	3.78-004	22000.0
Mean/Tot.	3.66-004	6.20-003	32.15-002	21.00+000	21.00+000	32.15-002	6.20-003	3.66-004	100000.0

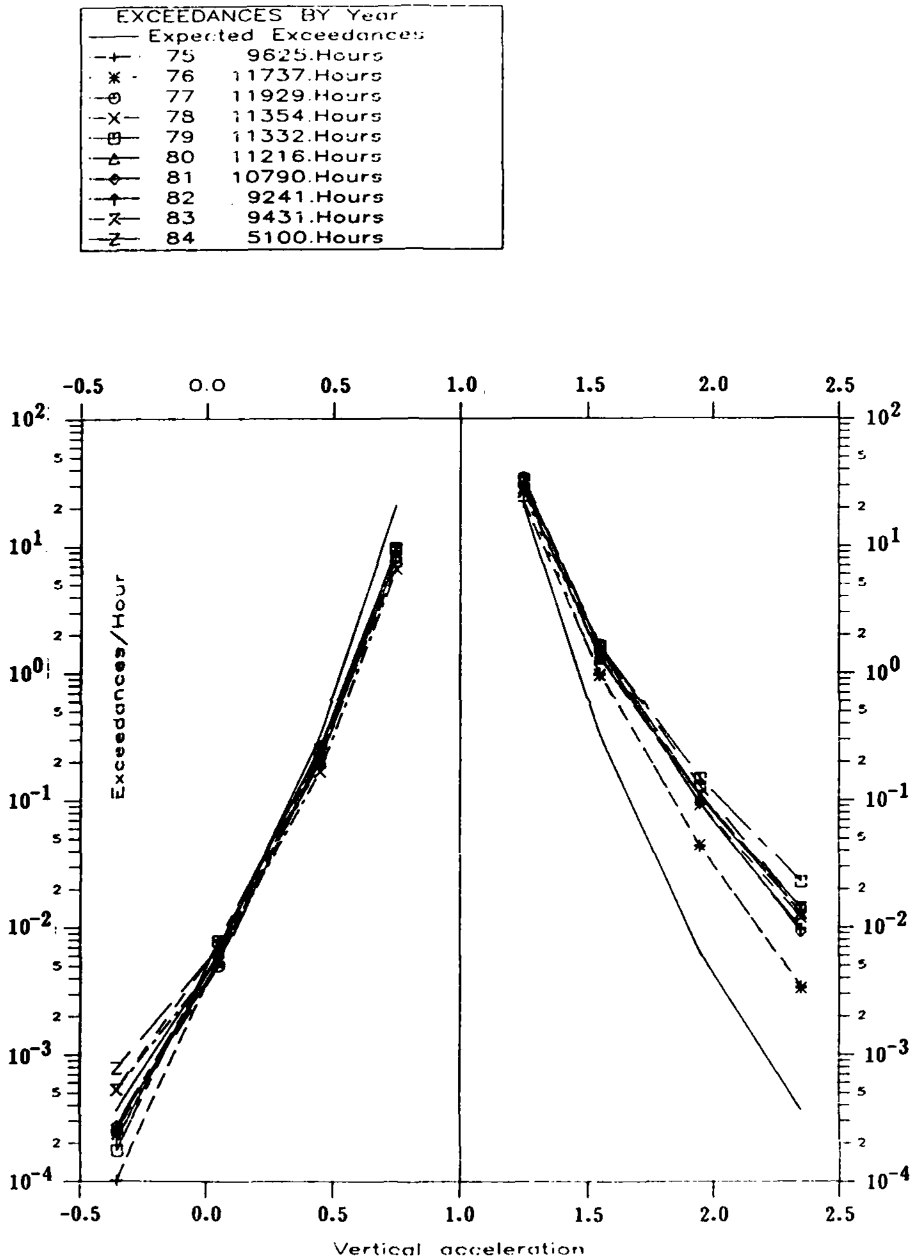

FIG. 1: YEARLY VARIATION OF LOAD SPECTRA EXPERIENCED BY RAAF CARIBOU AIRCRAFT.

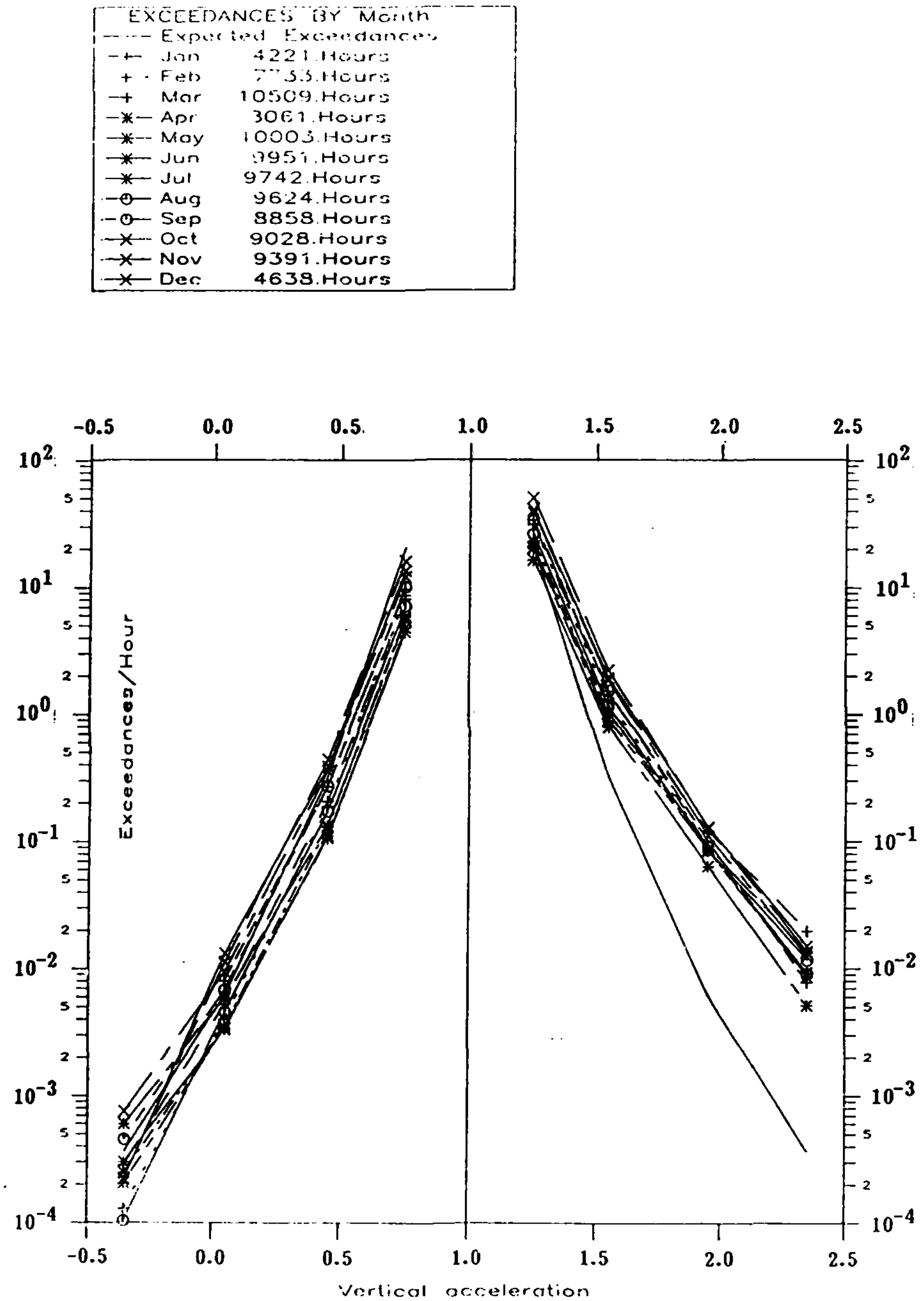

FIG. 2: CALENDAR MONTH (SEASONAL) VARIATION OF LOAD SPECTRA EXPERIENCE BY RAAF CARIBOU AIRCRAFT.

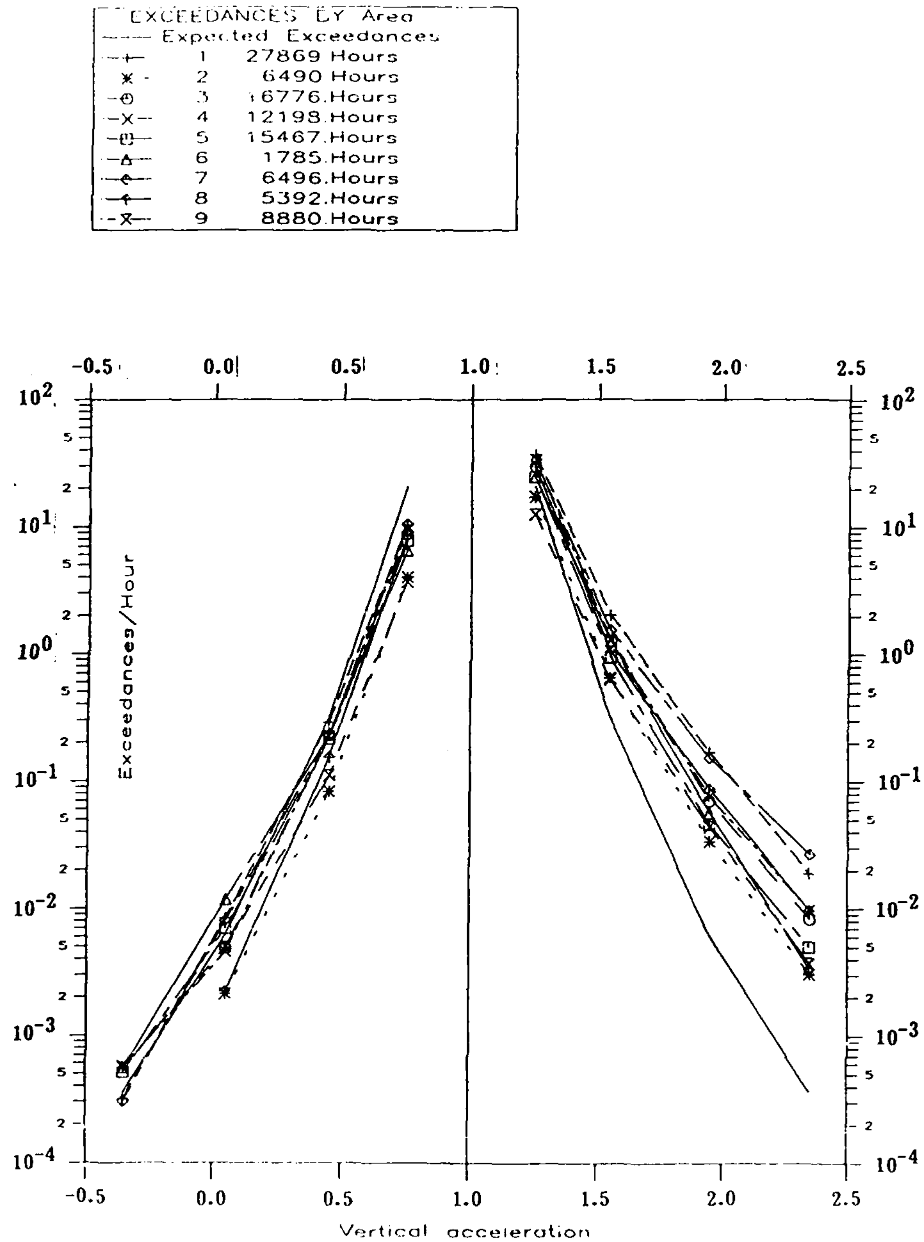

FIG. 3: GEOGRAPHIC VARIATION OF LOAD SPECTRA EXPERIENCED BY RAAF CARIBOU AIRCRAFT.

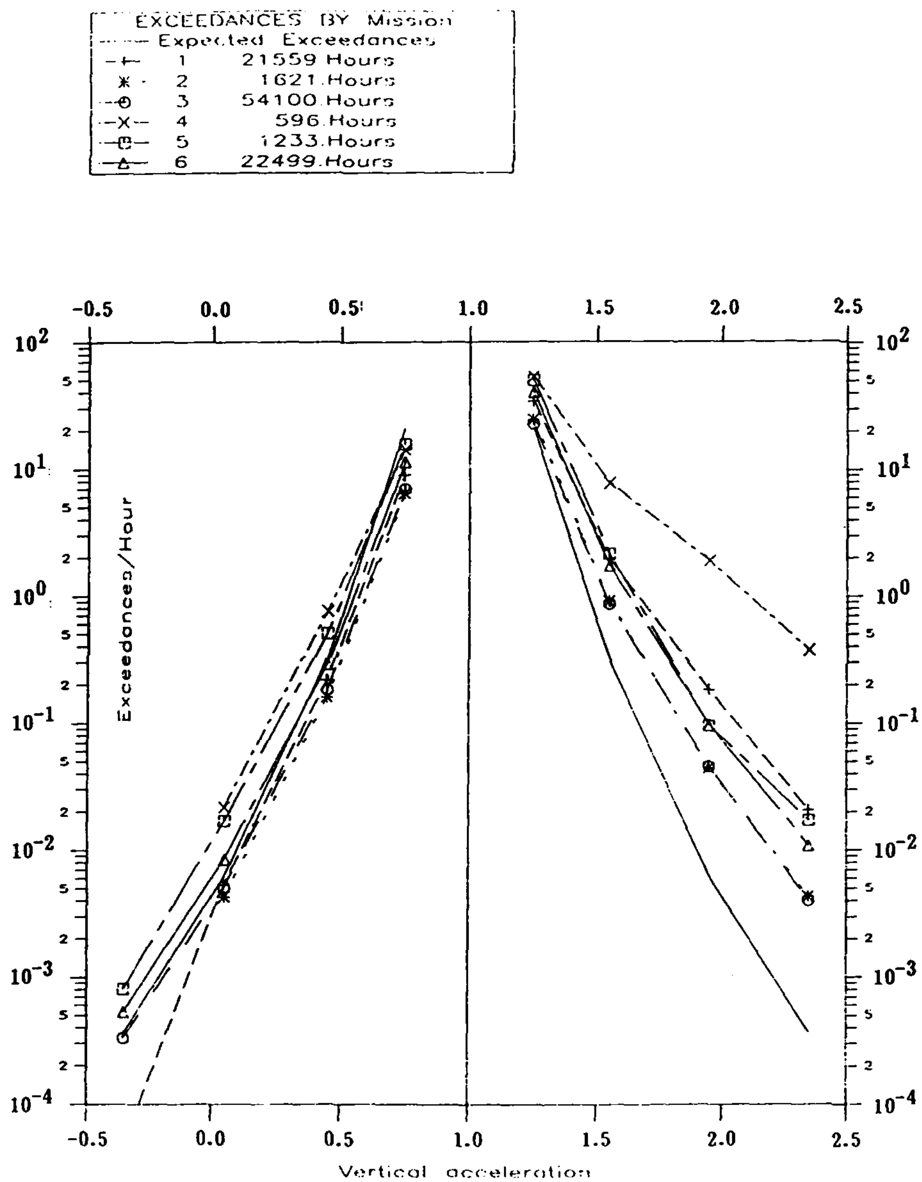

FIG. 4: TYPE OF FLYING (MISSION) VARIATION OF LOAD SPECTRA EXPERIENCED BY RAAF CARIBOU AIRCRAFT.

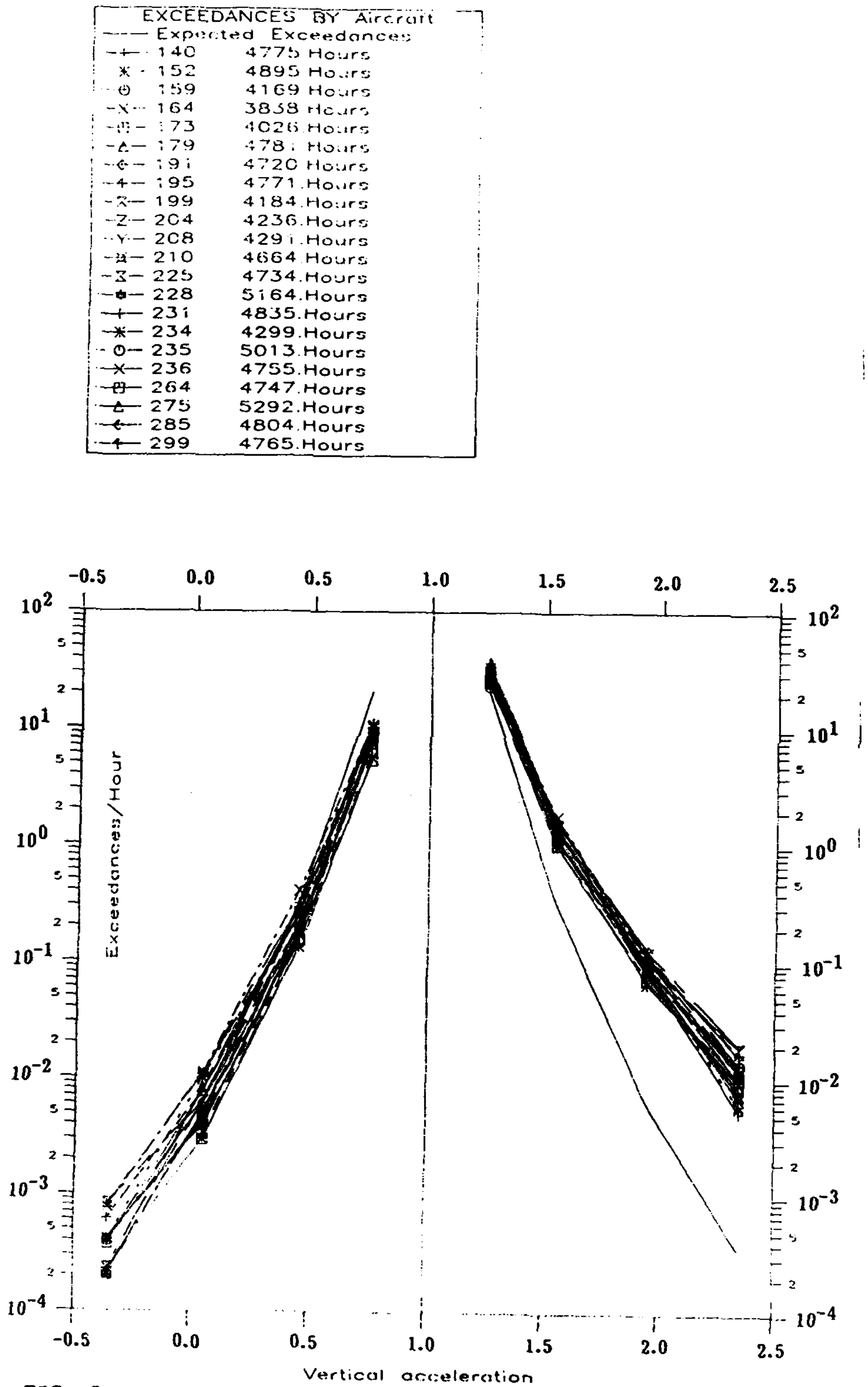

FIG. 5: AIRCRAFT TO AIRCRAFT VARIATION OF LOAD SPECTRA EXPERIENCED BY RAAF CARIBOU AIRCRAFT.

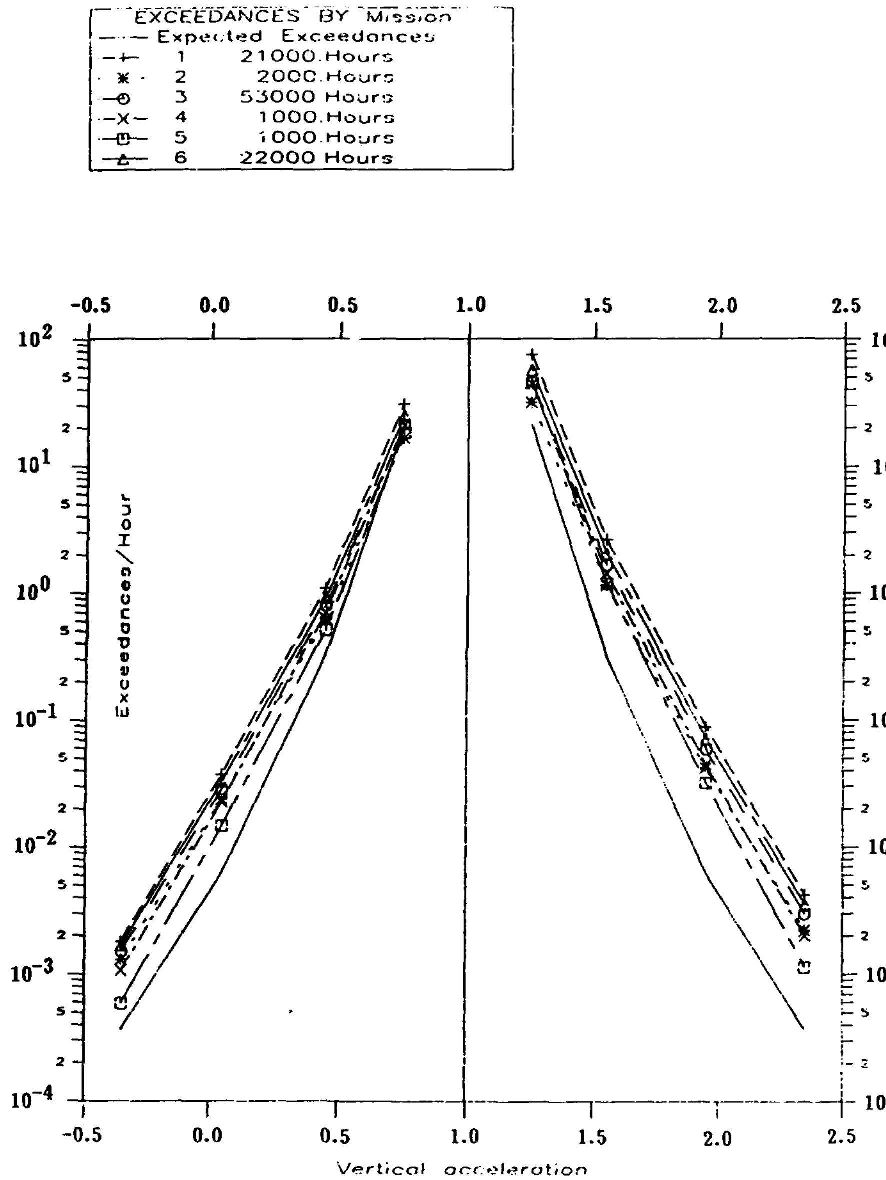

FIG. 6: PREDICTED TYPE OF FLYING (MISSION) VARIATION OF LOAD SPECTRA USING ESDU DATA ITEM 69023.

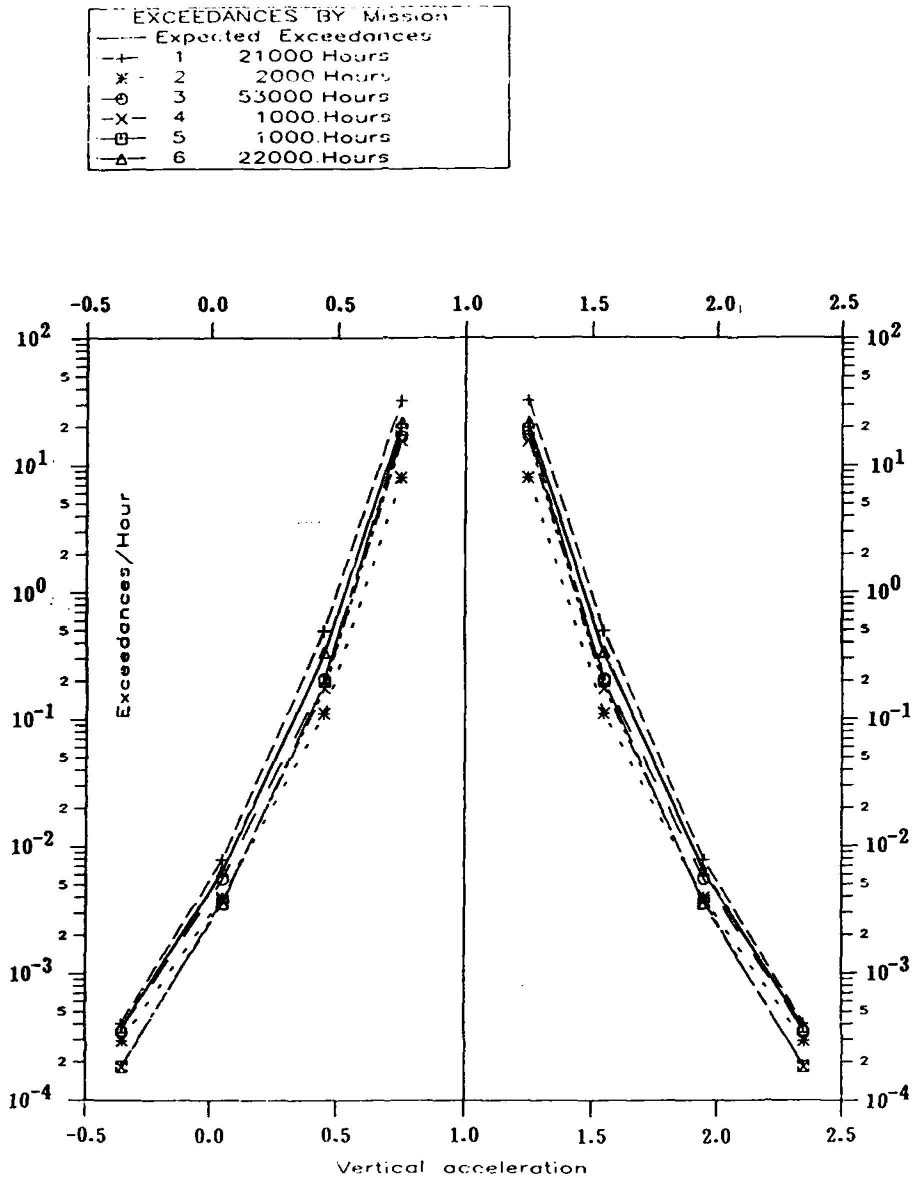

FIG. 7: PREDICTED TYPE OF FLYING (MISSION) VARIATION OF LOAD SPECTRA USING US MILSPEC A8861A (1971).

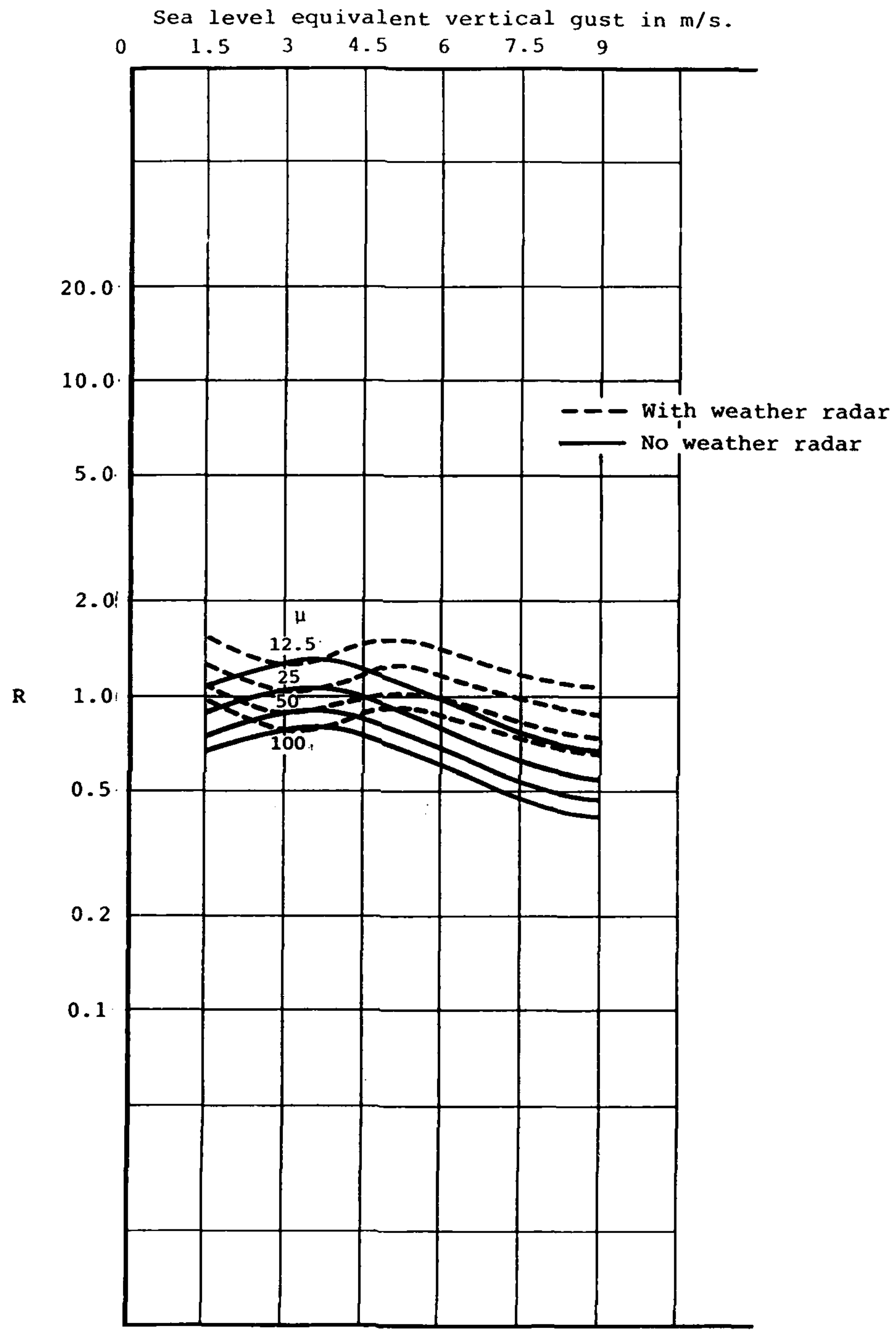

FIG. 8: RATIO, R, OF NUMBER OF GUST EXCEEDANCES COMPUTED BY POWER SPECTRAL METHOD TO NUMBER COMPUTED BY DISCRETE GUST METHOD FOR AN AIRCRAFT HAVING THE CONFIGURATION OF A CARIBOU AND THE VARIOUS MASS PARAMETERS (μ) SHOWN, AND FLYING AT AN ALTITUDE OF 500 ft.

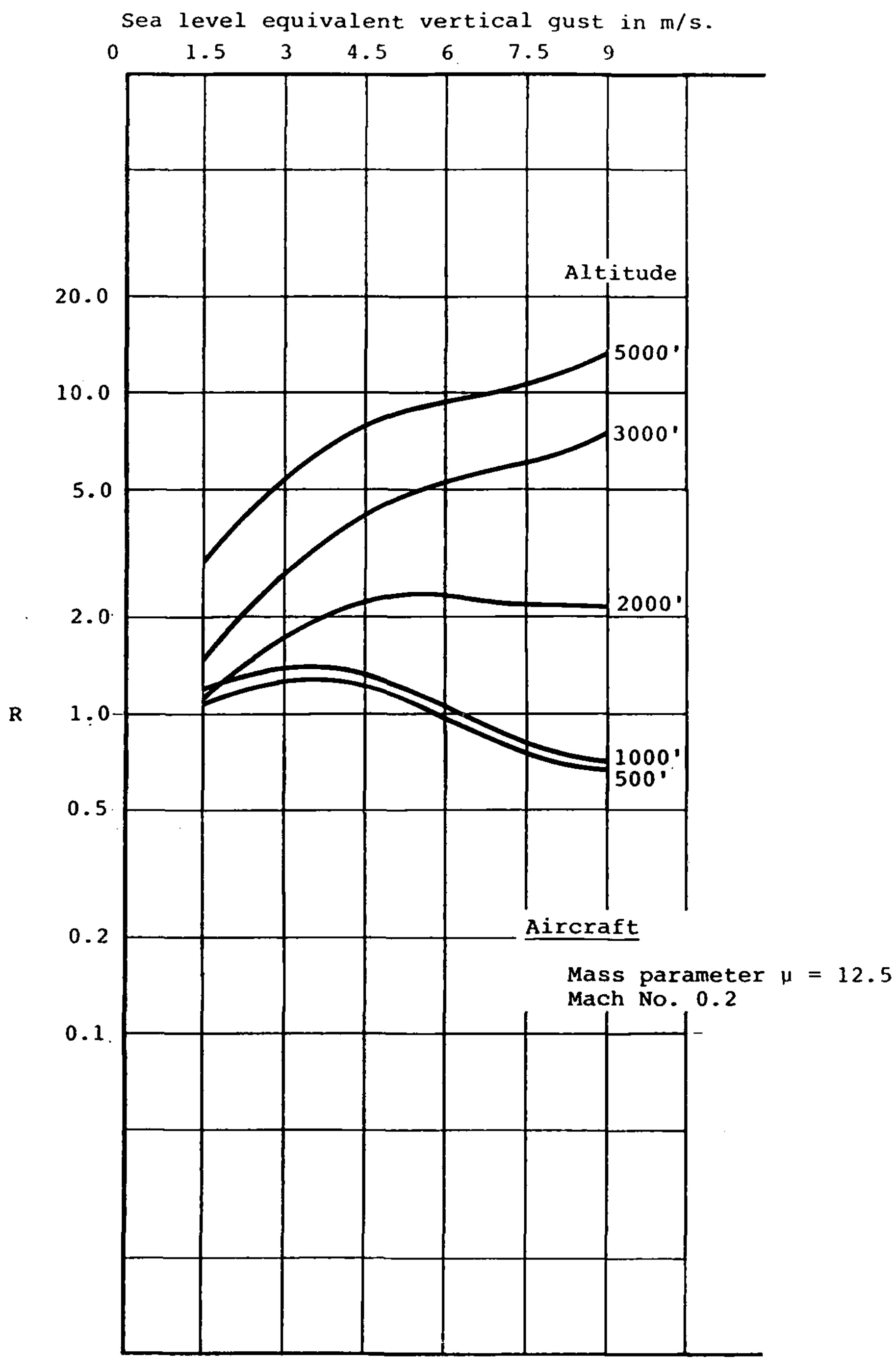

FIG. 9(a): RATIO, R, OF NUMBER OF GUST EXCEEDANCES COMPUTED BY POWER SPECTRAL METHOD TO NUMBER COMPUTED BY DISCRETE GUST METHOD FOR A CARIBOU AIRCRAFT FLYING AT THE VARIOUS ALTITUDES SHOWN. (AIRCRAFT WITHOUT WEATHER RADAR.)

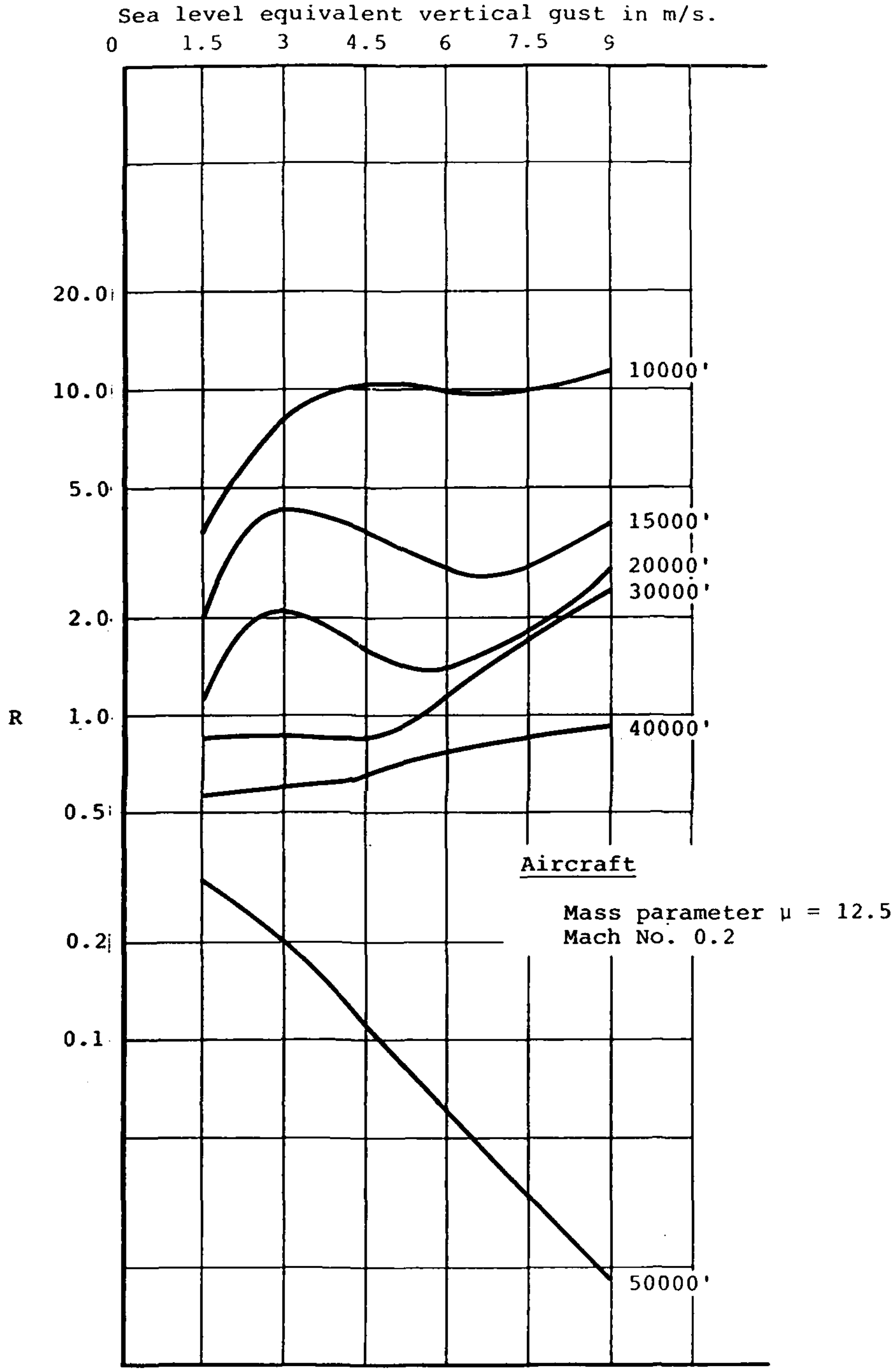

FIG. 9(b): RATIO, R, OF NUMBER OF GUST EXCEEDANCES COMPUTED BY POWER SPECTRAL METHOD TO NUMBER COMPUTED BY DISCRETE GUST METHOD FOR A CARIBOU AIRCRAFT FLYING AT THE VARIOUS ALTITUDES SHOWN. (AIRCRAFT WITHOUT WEATHER RADAR.)

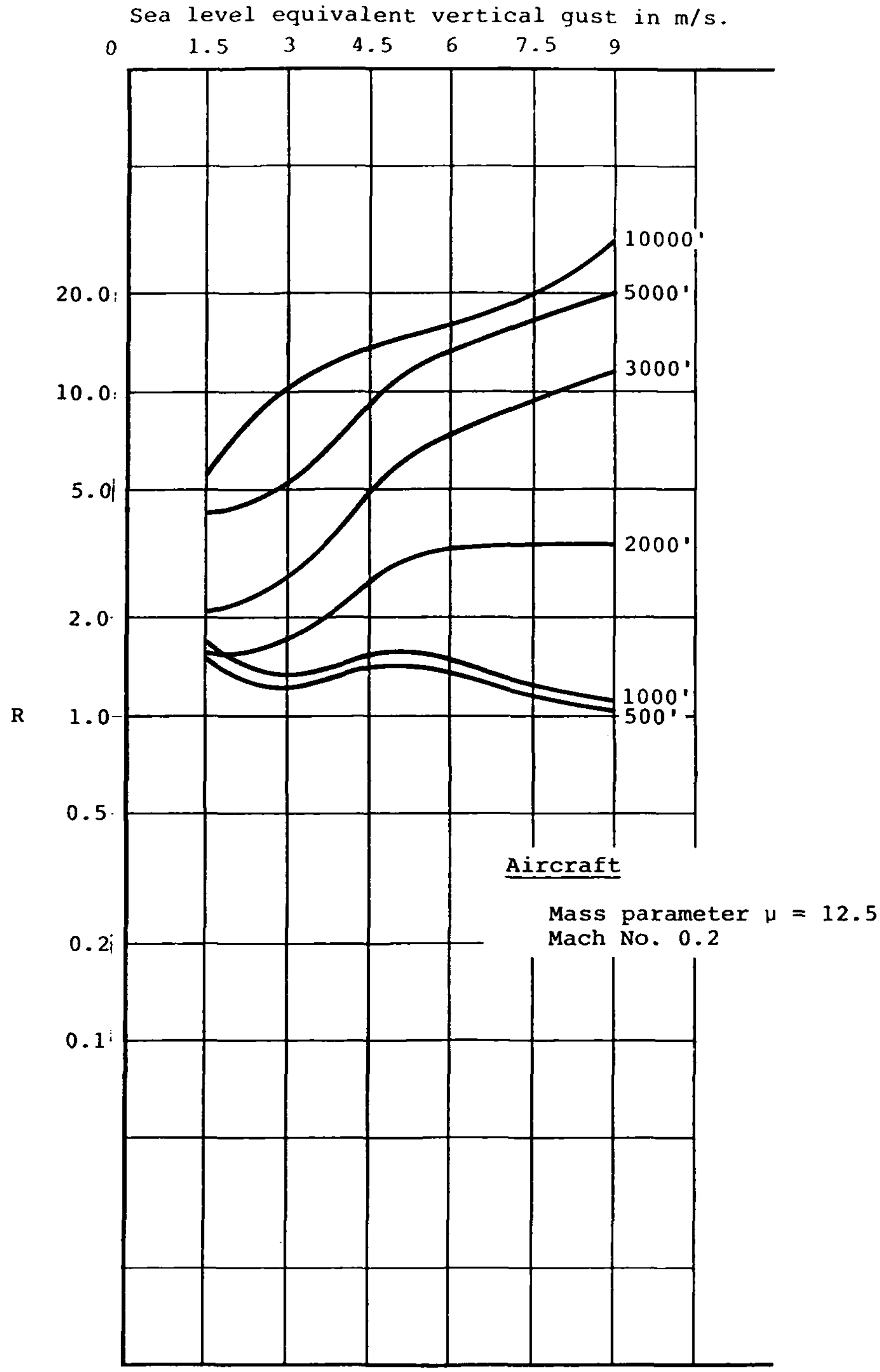

FIG. 10(a): RATIO, R, OF NUMBER OF GUST EXCEEDANCES COMPUTED BY POWER SPECTRAL METHOD TO NUMBER COMPUTED BY DISCRETE GUST METHOD FOR A CARIBOU AIRCRAFT FLYING AT THE VARIOUS ALTITUDES SHOWN. (AIRCRAFT WITH WEATHER RADAR.)

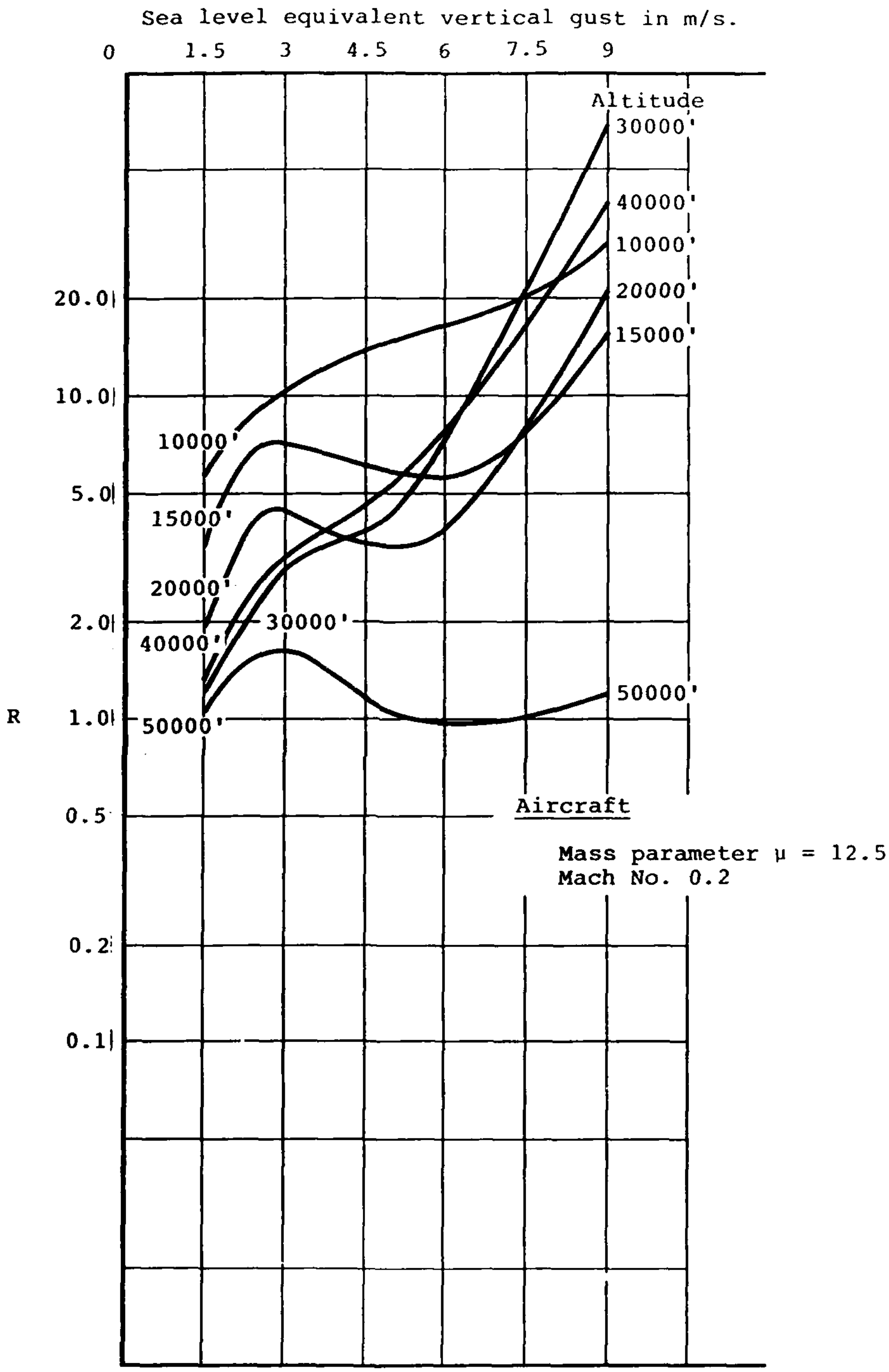

FIG. 10(b): RATIO, R, OF NUMBER OF GUST EXCEEDANCES COMPUTED BY POWER SPECTRAL METHOD TO NUMBER COMPUTED BY DISCRETE GUST METHOD FOR A CARIBOU AIRCRAFT FLYING AT THE VARIOUS ALTITUDES SHOWN. (AIRCRAFT WITH WEATHER RADAR.)

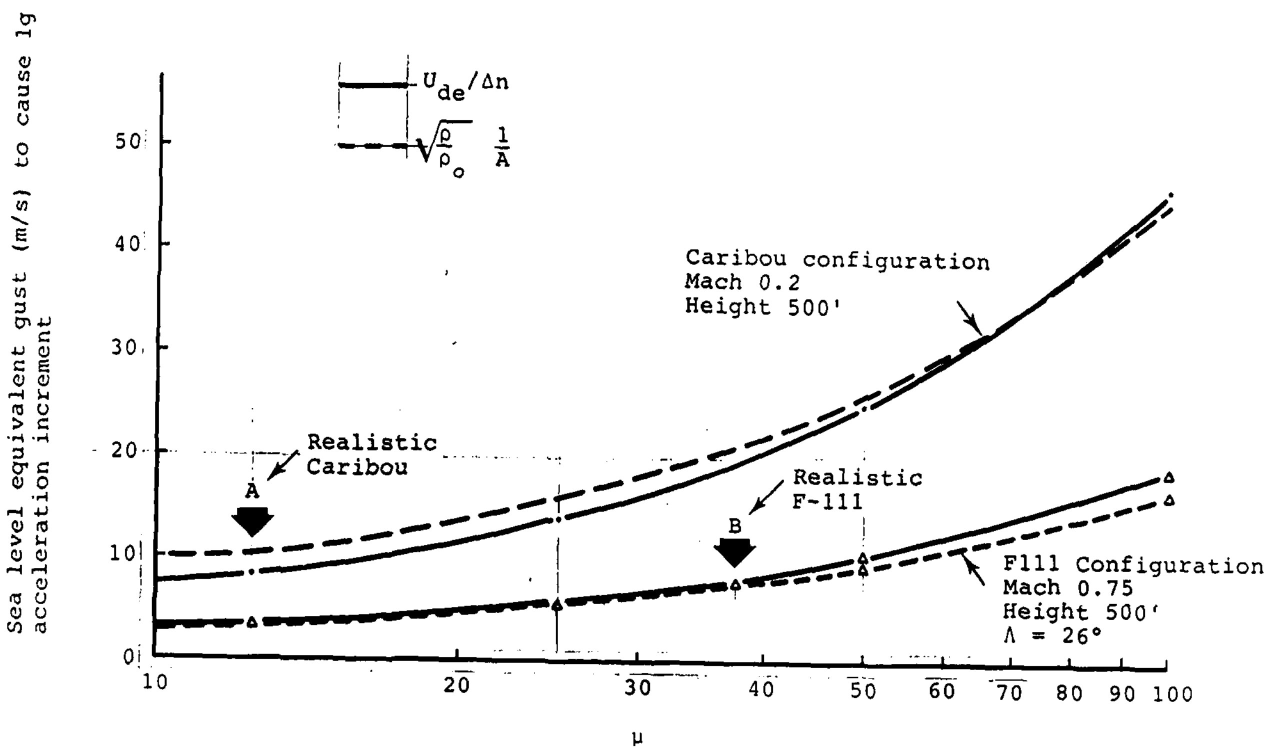

FIG. 11: TRANSFER FUNCTIONS (GUST VELOCITY TO CAUSE 1g ACCELERATION INCREMENT) COMPUTED BY DISCRETE GUST AND POWER SPECTRAL METHODS FOR AIRCRAFT HAVING THE CONFIGURATIONS OF A CARIBOU AND AN F-111 AND VARYING MASS PARAMETERS

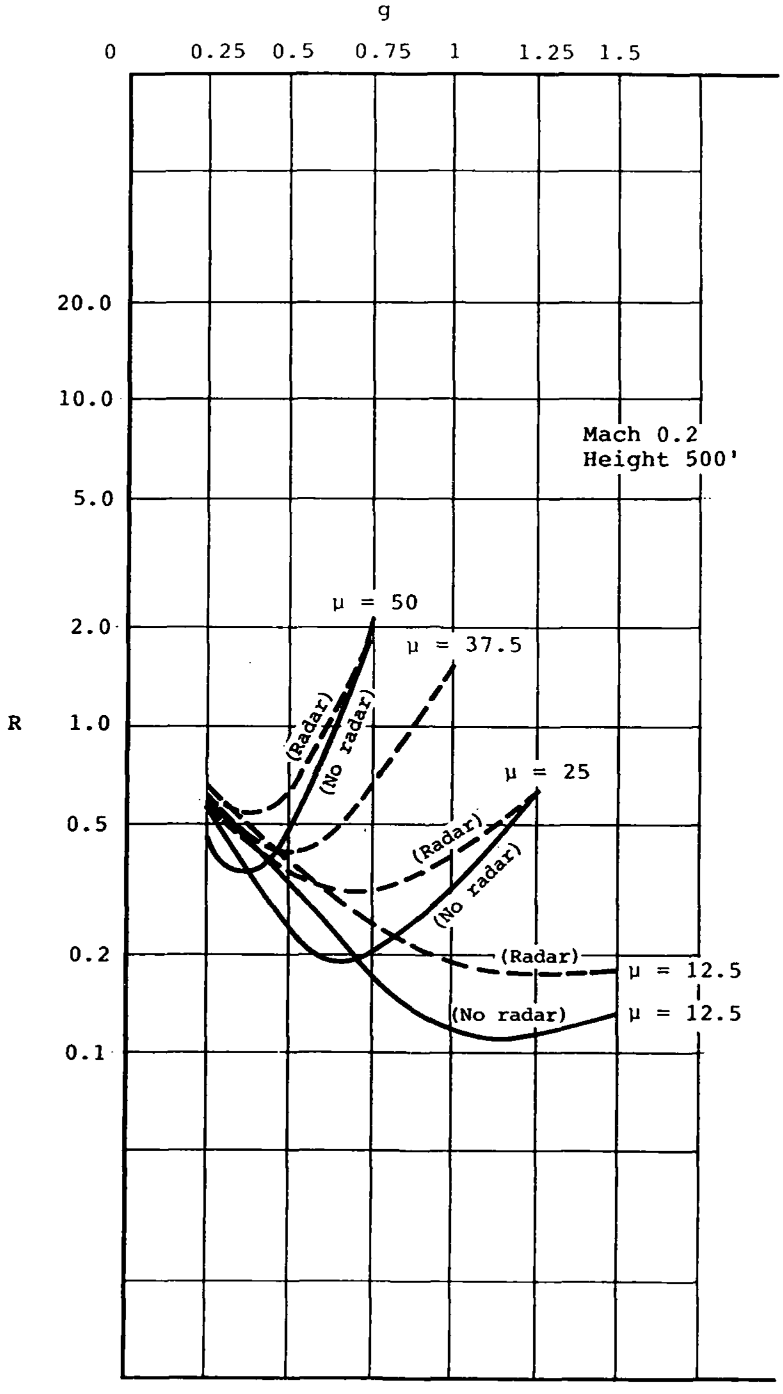

FIG. 12: RATIO, R, OF NUMBER OF LOAD EXCEEDANCES COMPUTED BY POWER SPECTRAL METHOD TO NUMBER COMPUTED BY DISCRETE GUST METHOD FOR AN AIRCRAFT HAVING THE CONFIGURATION OF A CARIBOU AND THE VARIOUS MASS PARAMETERS SHOWN.

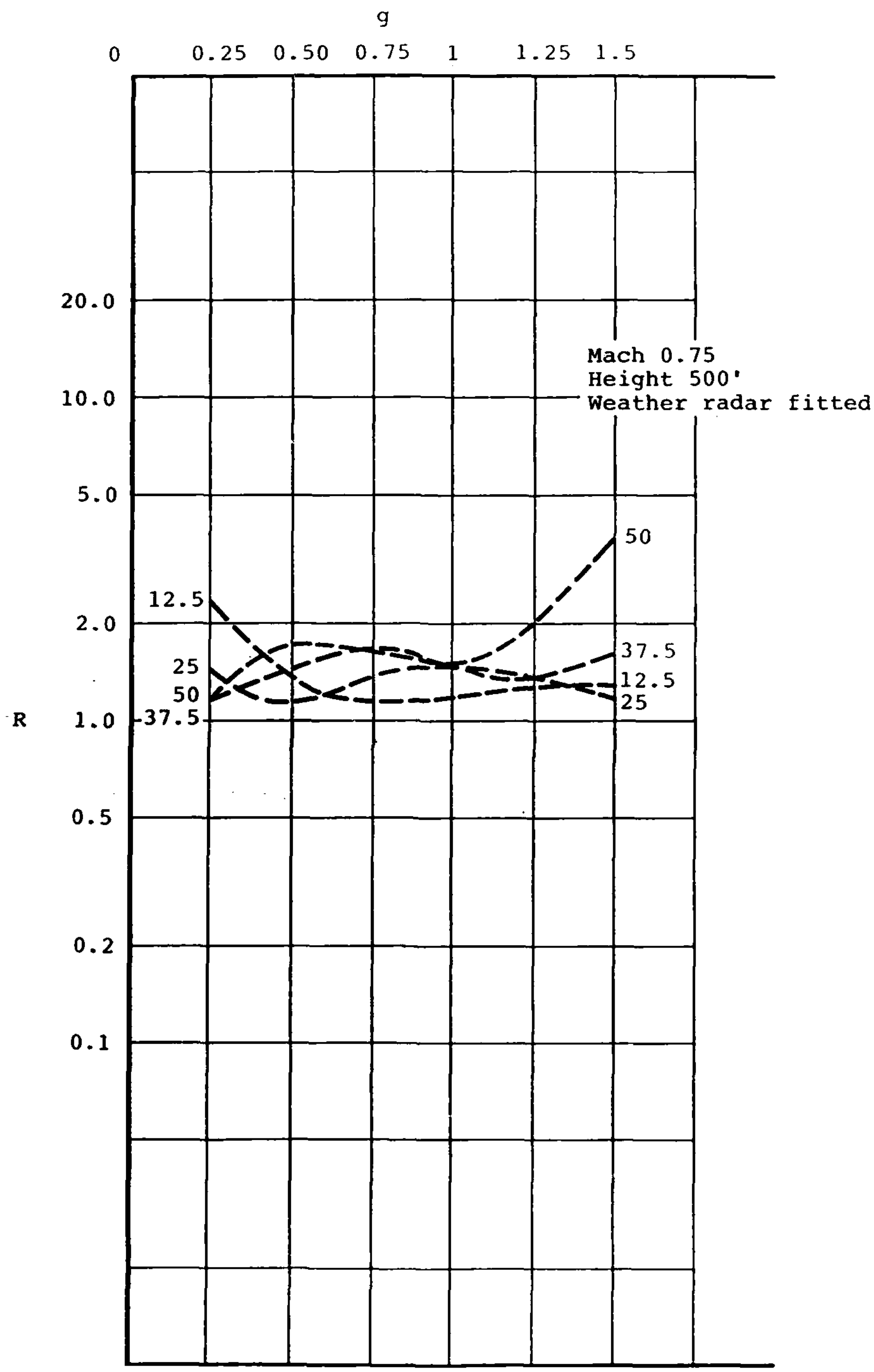

FIG. 13: RATIO, R, OF NUMBER OF LOAD EXCEEDANCES COMPUTED BY POWER SPECTRAL METHOD TO NUMBER COMPUTED BY DISCRETE GUST METHOD FOR AN AIRCRAFT HAVING THE CONFIGURATION OF AN F-111 ($\Lambda = 26°$) AND THE VARIOUS MASS PARAMETERS SHOWN.

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14. DESCRIPTORS	15. DRDA SUBJECT CATEGORIES
Atmospheric Turbulence Gust Loads Fatigue Life De Havilland Caribou DHC-4 Aircraft	0051c

16. ABSTRACT

Load spectra for the Australian fleet of Caribou transport aircraft are presented and compared with the ESDU 69023 (discrete gust) model and the US MILSPEC 8861A (power spectral) model.

The gust load spectra are best predicted by the US MILSPEC model. The most frequent manoeuvre loads are well predicted by the ESDU model, although the rarer, high amplitude, manoeuvre loads occur more frequently than that model predicts.

PAGE CLASSIFICATION
UNCLASSIFIED
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16. ABSTRACT (CONT.)		
17. IMPRINT AERONAUTICAL RESEARCH LABORATORY, MELBOURNE		
18. DOCUMENT SERIES AND NUMBER AIRCRAFT STRUCTURES TECHNICAL MEMORANDUM 489	19. COST CODE 271085	20. TYPE OF REPORT AND PERIOD COVERED
21. COMPUTER PROGRAMS USED		
22. ESTABLISHMENT FILE REF.(S) M2/518		
23. ADDITIONAL INFORMATION (AS REQUIRED)		